

INFORMATION CONTENT OF DIFFERENT RUNWAY LIGHTING PATTERNS

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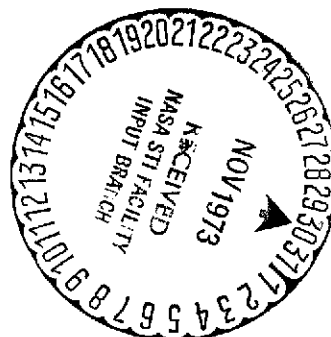
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16. Abstract Commercial pilots sitting before and looking at a television screen, on which were presented moving dots or bars simulating an approach to a visual landing system, were asked to discriminate between level flight or flight with change in altitude in the sense of a descent. There were 4 patterns of light markings: single row, double row, single crossbars and double crossbars. Changes in altitude were significantly better observed in the double patterns than in the single patterns (angle α is larger than angles α' and α'' , and the larger the angle, the more its increase by the same amount of descent). For the same reason it is obvious that the single crossbars are better than the single row. At first glance it is not clear why the double row turned out to be better than the double crossbars. Possibly in the latter pattern less valid angle α' was more conspicuous to the observer than the also available larger angle α .					
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INFORMATION CONTENT OF DIFFERENT RUNWAY LIGHTING PATTERNS

J. Kylstra and J. Hoogerheide¹

Introduction

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Until such time as the approach and landing of aircraft can be enabled by a fully automated system, the pilot will be obliged to execute this last leg of his flight exclusively on the basis of visual information -- often under conditions of minimum visibility. An urgent necessity is that the flier -- especially during the critical last hundred feet -- be continuously supplied with the maximum amount of information in a manner both simple and unambiguous.

In principle, all methods of runway lighting are based on a single or a double row of lights, sometimes combined with bar-shaped elements vertical or even parallel to the runway.

The question of which configuration of these lights should be given preference constituted the object of a comparative study.

Since of all the data that the pilot requires the first and foremost place is occupied by continuous information about his altitude and in order not unduly to complicate this study and thus render it less reliable, we decided to adopt as our criterion the minimally detectable change in altitude for the four basic types of runway markings, namely:

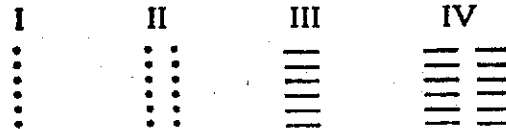
¹ With technical assistance from J. Th. Eernst and statistical processing by L. F. W. de Klerk (both from the Institute of Sensory Physiology RVO/TNO).

* Numbers in the margin indicate pagination in the foreign text.

- I. Single row
- II. Double row
- III. Single crossbars
- IV. Double crossbars

Thus:

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Now we shall describe in greater detail the manner of presentation of these patterns. In contradistinction to an earlier study by G. ten Doesschate ("The perception of parallels," 1954 and 1955), in which static pictures were utilized, we tried, by presenting our experimental subjects with moving pictures, to approximate as closely as possible what is actually observed from an aircraft. A very good consensus of opinion was achieved by the selected experimental subjects.

Some Theoretical Considerations

If we ask ourselves what data are necessary to the pilot during flight and landing, our answer can only be as follows:

- I. Position of the aircraft with respect to its three axes (attitude);
- II. Its motion about and in the direction of its three axes;
- III. Position of the intersection of axes with respect to the earth (scil. the runway);
- IV. Motion of the intersection of axes with respect to the earth.

For the acquisition of these data under VFR the pilot has at his disposal the following:

For I: a. Horizon (roll) or artificial horizon,
b. Position of horizon with respect to cockpit cutoff (pitch) or artificial horizon,
c. Position with respect to the direction of motion, traversing

For II:	a. IAS	}	dependent on settings always instrumental
	b. Rate of descent		
	c. Slip		

For III: a. Estimate of altitude with respect to the earth
b. Estimate of distance to known points

For IV: a. Determination of rhumb line, drift
b. Determination of angle of descent.

For landing, the pilot must refer to the outside world: bank and pitch indication, traverse (I. a.b.c.), altitude and angle of trajectory, position with respect to the longitudinal direction of the trajectory (scil. aiming point).

Under VFR the following laws hold:

The point where the trajectory intersects the surface of the earth is the only point in the visual field that betrays no apparent motion. This point must coincide with the aiming point (1) (see Fig. 1) and the ILS reference point if the aircraft follows the ILS glide path.

If, in the case of a double pattern (II and IV), we designate by h the distance between any point x of the runway and the horizon, as this distance is observed in the picture plane; by b the

Observed width of the runway at that point; and if the actual width of the runway is W and the altitude is H ; then:

$$H = \frac{W}{b} \times h$$

Moreover, the picture plane (FRV) presents itself as a trapezium whose raised sides have a virtual point of intersection. If we designate by a the angle at which these sides intersect one another, then the following formula holds:

$$H = 1/2W \cot 1/2a$$

If we are considering the case of a single-row system, then the following formula holds:

$$H = \frac{A \times d}{D} \quad \text{or} \quad H = A \tan U \quad (\text{see Fig. 1})$$

where: A = the distance between observer and aiming point; d = the distance between two consecutive lights in the picture plane; D = the distance between two consecutive lights on the runway; U = the angle at which the aiming point with respect to the horizon is observed.

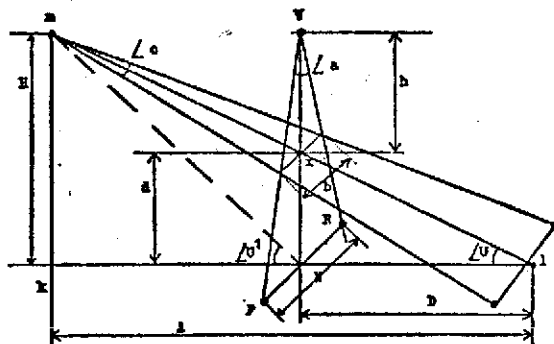


Fig. 1.

In order to be able to observe a change in altitude, the following clues can be used:

- 1) The change in $H = 1/2W \cot 1/2a$.
- 2) The change in $H = A \tan U$
- 3) The angular velocity with /24 respect to the observer is inversely proportional to altitude and distance

- 4) The light intensity for the observer increases quadratically with decreasing altitude and distance.

It is clear from the foregoing that introduction of transverse markings of known size not only provides an easy-to-interpret parameter in addition to those already present, but also constitutes a clue to the position of the horizon with respect to the aircraft and thus an indication of pitch.

Moreover, under conditions of poor visibility, in the case of the double row, as well as in the case of the single crossbars, there are always two points present at the same time for the observer; in the case of the single row, only one after another.

Thus we may already expect a priori that the introduction of transverse markings of known and uniform length will improve the pilot's performance.

It ought to be noted that with the apparatus at our disposal only a narrow runway could be realized. For the change in altitude in a comparative study of runway lighting patterns clues 3 and 4 are identical for all patterns; both clues 1 and 2 play a role in the case of a double row; in the case of a single row, only clue 2 will be present.

For clue 1 the following holds: $H = 1/2W \cot 1/2a$.

For clue 2 the following holds: $H = (A - d) \tan U'$.

For the change in altitude, then, the following holds

$$\begin{array}{ll} \text{clue 1. } a = \tan^{-1} \frac{1/2W}{H} & \frac{da}{dH} = - \frac{1/2W}{H^2 + (1/2W)^2} \\ \text{clue 2. } U' = \tan^{-1} \frac{H}{A-D} & \frac{dU'}{dH} = + \frac{(A-D)}{H^2 + (A-D)^2} \end{array}$$

Given these formulas and the data about the presented runway (see Experimental Setup), the angular change/ft for both clues can be figured out.

These are:

Clue I: given $H = 100$ ft $1/2W = 25$ ft

$$\frac{da}{dH} = \frac{-25}{100^2 + 25^2} \times 57 = -0.16^\circ/\text{ft}$$

Clue II: given Fig. 1 and $U' = 7^\circ$, $H = 100$ ft

$$\begin{aligned} A-D &= 100 \cot 7^\circ = 800 \text{ ft} \\ \frac{dU'}{dH} &= \frac{800}{100^2 + 800^2} \times 57 = 0.075^\circ/\text{ft} \end{aligned}$$

In order to put these theoretical considerations to the test, /25 we investigated a number of commercial fliers with the aid of the experimental setup described below.

Experimental Setup

After a very time-consuming and protracted preliminary study we finally succeeded in finding an experimental setup in which the experimental subject could be presented with a dynamic pattern that was in satisfactory keeping with the picture that the pilot observes from an aircraft during poor visibility. The system, to be sure, has faults of which we are only too aware; but these faults have the same effect in all tests, so that they raise no difficulty for a comparative study.

On a tabletop we project endless films showing the different configurations that are to be investigated. The projected picture is observed through a television camera that relays the picture to a monitor set up in a darker room. The television camera is so set up that it can be vertically moved with respect to the table.

By moving this camera up and down we can simulate a change in altitude as it appears incident to the landing of an aircraft flying toward a 50-ft wide runway on which the lights are longitudinally spaced from each other at 200-ft intervals. The approach speed is ± 400 km/h. The angle at which the first row of horizontal lights is observed is angle U' (see Fig. 1), which amounts to 7° . The altitude changes from 100 ft to 40 ft. Presented are the earlier mentioned patterns I, II, III, and IV, each pattern under two lighting conditions, namely:

Condition I: contrast 100%, brightness 20 cd/m^2

Condition II: contrast 30%, brightness 0.6 cd/m^2 .

The angular size of the lights of patterns I and II with respect to the experimental subject is $\pm 20^\circ$.

The angular size of the lights of patterns III and IV is $68'$ in the horizontal direction and $17'$ in the vertical direction.

Instruction of Experimental Subjects

The experimental subject was instructed to indicate by the pressing of a button that moment at which he, starting from an altitude of 100 ft, detected a change in altitude.

The values shown in Tables I and II are the averages of 10 of these recordings expressed in ft of altitude.

Experiments

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Experiment 1

This experiment was carried out with 35 experienced pilots who were presented with the four patterns in an arbitrary sequence. Each experimental subject was presented with each pattern 10 times while lighting condition I prevailed.

Table I shows the averages of these 35 experimental subjects for each pattern.

TABLE I

	Single row	Double row	Single crossbars	Double crossbars
Patterns	I	II	III	IV
H	79.4	89.2	84.9	87.8

H in ft = the altitude at which a change was detected.

Experiment II

This experiment was carried out with 16 experienced pilots divided into two groups:

Group I under lighting condition I and

Group II under lighting condition II;

while the order of presentation of the samples was done according to a latin square method.

Experimental subjects	Patterns	Experimental subjects	Patterns
1 5	I II III IV	9 13	I II III IV
2 6	II III IV I	10 14	II III IV I
3 7	III IV I II	11 15	III IV I II
4 8	IV I II III	12 16	IV I II III
Condition I		Condition II	

Table II shows the averages of eight experimental subjects for each pattern

Analysis of the variance of the experimental data showed /27
two significant differences, viz. among experimental subjects with regard to the threshold value for all patterns ($F = 4.85$; $p < 0.01$) and between patterns ($F = 36.39$; $p < 0.001$); no other difference appeared to be significant.

TABLE II

	Single row	Double row	Single crossbars	Double. crossbars
Patterns	I	II	III	IV
Condition I	53.03	74.18	60.52	66.63
Condition II	51.55	76.02	61.85	63.60

For correlated observations compared among themselves the Student t test showed the following:

The double row and double crossbar patterns are significantly better than the single row and single crossbar patterns ($t = 4.85$; $\alpha < 0.005$).

The double row is significantly better than the double crossbars ($t = 4.01$; $\alpha < 0.005$).

The single crossbars are significantly better than the single row.

Discussion

Fig. 2 shows what configurations the experimental subjects got to see on the monitor at the start of each descent. Qualitatively it is simple to elucidate the experimental results on theoretical grounds.

For the detection of a change in altitude the double patterns are clearly better than the single patterns because in the double patterns an important clue is provided by angle α (i.e., the angle that the rows of beacons make with each other as they are mentally extended toward the horizon).

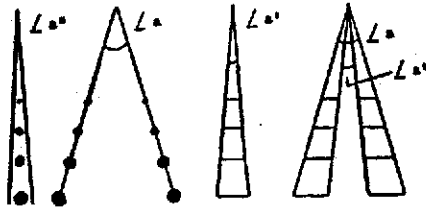


Fig. 2.

To be sure, also in the case of the single crossbar there is a question of a small angle if we connect the outermost points of the bars with each other. But this angle is much smaller than angle a , and the change in this small angle for one and the same change in altitude is smaller than in the case of the larger angle a .

This fact also elucidates the experimental result that the single crossbars enable better detection of a change in altitude than the single row because in the case of the latter, angle a'' amounts to only 20 min. Unexplained remains the fact that the double row is better than the double crossbars. Theoretically, we /28 would expect the double crossbars to be better than the double row because in addition to angle a , angle a' (albeit less valid) also gives a clue. We shall endeavor to find an explanation for this.

Sanders (1963) has shown that the so-called functional visual field becomes narrower with increasing complexity of the visual tasks. We might say that as the visual task becomes more involved (for example, incident to the presentation of more clues), there is a tendency to confine oneself to the more central parts of the visual field. We deem it possible that in contemplating the double crossbar pattern, our experimental subjects just confined their attention to the open space between the bars (angle a') to the detriment of angle a , which could also be extracted from this pattern.

If the difficulty of discrimination remains the same, more attention will naturally be devoted to the configuration that is more centrally located in the visual field. In this selection of clues a role may perhaps be played by a habit that many pilots have formed by dint of practice, namely, the habit of focussing attention

to the "narrow gauge" beacons on the runway. Yet the difference in discrimination is much greater for a small angle than for a large one. The larger the angle becomes, the better is discrimination of a change in the angle because the change in angle per unit change in altitude becomes greater. For an altitude difference of 1 ft angle a increases by 0.15° while angle a' increases by only 0.024° .

Apparently the difference in difficulty of discrimination is so great that the double row, which is the only one to present angle a , allows better detection of a change in altitude than do the double crossbars.

We are inclined to summarize the experimental results in the following general and descriptive terms.

1. Detection of a change in altitude improves as (within certain limits) more clues are presented.

2. This, however, is only true if the clues are of dissimilar natures, such as a change in angle, a change in length, a change in brightness, a change in angular velocity.

3. If a certain clue (angle or length) is broken up into pieces, each one of which in itself constitutes a less valid clue than the total, confusion may occur: the attention may favor a partial clue, so that the pattern loses out to a pattern that presents the clue in an uncomplicated form.

4. It is possible that points 1 to 3 above also apply to absolute estimates of altitude. /29

5. All clues are not equally important. Particularly relevant from the phenomenal point of view are changes in angles (double patterns are better than single patterns).

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